Hata and CCIR Formulas[1]

- Following extensive measurements of urban and suburban radio propagation losses, Okumura et al. published many empirical curves useful for cellular systems planning.

    - These empirical curves were subsequently reduced to a convenient set of formulas known as the Hata model that are widely used in the industry.

- The basic formula for the median propagation loss given by Hata is

$$\text{L (dB)} = 69.55 + 26.16\,\text{log}_{10} f_{\text{MHz}} - 13.82\,\text{log}_{10} h_1 - \text{a}(h_2) \\ + (44.9 - 6.55\,\text{log}_{10} h_1)\,\text{log}_{10} d_{\text{km}} - K$$

where $h_1(30\text{-}200)$ and $h_2(1\text{-}10)$ are base station and mobile antenna heights in meters, respectively, $d_{\text{km}}(1\text{-}20)$ is the link distance in kilometers, and $f_{\text{MHz}}(150\text{-}1500)$ is the center frequency in megahertz.

- The term a(h_2) is an antenna height-gain correction factor that depends upon the environment. It equals zero for $h_2 = 0$.

- The factor K is used to correct the small city formula for suburban and open areas.

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[1] From J. S. Lee and L. E. Miller, *CDMA Systems Engineering Handbook*. Boston: Artech House, 1998; and NTIA's LMS calculator help file.

Hata Model Parameters

Type of area	a(h_2)	K
open	$(1.1\,\log_{10} f_{MHz} - 0.7)h_2 - (1.56\,\log_{10} f_{MHz} - 0.8)$	$4.78(\log_{10} f_{MHz})^2 - 18.33\,\log_{10} f_{MHz} + 40.94$
suburban		$2[\log_{10}(f_{MHz}/28)]^2 + 5.4$
medium-small city		0
large city ($f_{MHz} > 300$)	$3.2(\log_{10} 11.75 h_2)^2 - 4.97$	0
large city ($f_{MHz} < 300$)	$8.29(\log_{10} 1.54 h_2)^2 - 1.10$	0

- The category of “large city” used by Hata implies building heights greater than 15 m.
- At the cellular frequency of 850 MHz, the Hata model becomes

$$\mathrm{L}_{Hata} = 146.18 + (44.9 - 6.55\,\log_{10} h_1)\log_{10} d_{km} - \mathrm{a}(h_2) - 13.82\,\log_{10} h_1 - K$$

where

Type of area	a(h_2)	K
open	$2.52\,h_2 - 3.77$	28.26
suburban		9.79
medium-small city		0
large city	$3.2(\log_{10} 11.75 h_2)^2 - 4.97$	0

Extension of Hata Model to Longer Distances

- An empirical formula for extending the Hata Model to distances 20-100 km was developed by ITU-R and is given by

$$\mathrm{L}_{ITU}(\mathrm{dB}) = 69.55 + 26.16\,\mathrm{log}_{10} f_{\mathrm{MHz}} - 13.82\,\mathrm{log}_{10} h_1 - \mathrm{a}(h_2) \\ + (44.9 - 6.55\,\mathrm{log}_{10} h_1)(\,\mathrm{log}_{10} d_{\mathrm{km}})^b - K$$

where

$$b = \begin{cases} 1, & d_{\mathrm{km}} < 20 \\ 1 + (0.14 + 0.000187 f_{MHz} + 0.00107 h_1')(\mathrm{log}_{10}(d_{\mathrm{km}}/20))^{0.8}, & d_{\mathrm{km}} \geq 20 \end{cases}$$

and

$$h_1' = \frac{h_1}{1+7\times 10^{-6} h_1^2}$$

CCIR Model

- An empirical formula for the combined effects of free-space path loss and terrain-induced path loss was published by the CCIR (Comité Consultatif International des Radio-Communication, now ITU-R) and is given by

$$\mathrm{L}_{CCIR}(\mathrm{dB}) = 69.55 + 26.16\,\log_{10} f_{\mathrm{MHz}} - 13.82\,\log_{10} h_1 - \mathrm{a}(h_2) + (44.9 - 6.55\,\log_{10} h_1)\,\log_{10} d_{\mathrm{km}} - \mathrm{B}$$

where h_1 and h_2 are base station and mobile antenna heights in meters, respectively, d_{km} is the link distance in kilometers, f_{MHz} is the center frequency in megahertz, and

$$\mathrm{a}(h_2) = (1.1\,\log_{10} f_{\mathrm{MHz}} - 0.7)h_2 - (1.56\,\log_{10} f_{\mathrm{MHz}} - 0.8)$$

$$\mathrm{B} = 30 - 25\,\log_{10}(\%\text{ of area covered by buildings})$$

- This formula is the Hata model for medium–small city propagation conditions, supplemented with a correction factor, B.
  - The term B is such that the correction $\mathrm{B} = 0$ is applied for an urban area, one that is about 15% covered by buildings; for example, if 20% of the area is covered by buildings, then $\mathrm{B} = 30 - 25\,\log_{10} 20 = -2.5$ dB.

The Extended Hata Model

- For urban PCS applications at 1.5–2 GHz, it was found by a European study committee (COST 231) that the Hata model consistently underestimates path loss, and an "extended Hata model" was developed to correct the situation.

- The basic formula for the median propagation loss in dB given by the extended Hata propagation loss model is

$$\mathrm{L}_{XHata} = 46.33 + (44.9 - 6.55 \log_{10} h_1) \log_{10} d_{km} + 33.9 \log_{10} f_{MHz}$$
$$- \mathrm{a}(h_2) - 13.82 \log_{10} h_1 + C,$$

where

$$C = \begin{cases} 0, & \text{medium city and suburban areas} \\ 3, & \text{metropolitan (urban) centers} \end{cases}.$$

- The ranges of parameters for which this model is considered valid are the following:

$$1500 \leq f_{MHz} \leq 2000 \qquad 30 \leq h_1 \leq 200$$
$$1 \leq d_{\mathrm{km}} \leq 10 \qquad 1 \leq h_2 \leq 10.$$

The Hata-Davidson Model

- The Telecommunications Industry Association (TIA) recommends in their publication TSB-88A the following modification to the Hata model to cover a broader range of input parameters.

- The modification consists of the addition of correction terms to the Hata model:

$$\mathsf{L}_{HD} = \mathsf{L}_{Hata} + A(h_1,\, d_{\mathsf{km}}) - S_1(d_{\mathsf{km}}) - S_2(h_1,\, d_{\mathsf{km}}) - S_3(f_{MHz}) - S_4(f_{MHz},\, d_{\mathsf{km}})$$

in which A and S_1 are distance correction factors extending the range to 300 km, S_2 is a base station antenna height correction factor extending the range of h_1 values to 2500, and S_3 and S_4 are frequency correction factors extending frequency to 1500 MHz:

distance	$A(h_1,\, d_{\mathsf{km}})$	$S_1(d_{\mathsf{km}})$
$d_{\mathsf{km}} < 20$	0	0
$20 \le d_{\mathsf{km}} < 64.38$	$0.62137(d_{\mathsf{km}} - 20)[0.5 + 0.15\,\mathsf{log}_{10}(h_1/121.92)]$	0
$64.38 \le d_{\mathsf{km}} < 300$	$0.62137(d_{\mathsf{km}} - 20)[0.5 + 0.15\,\mathsf{log}_{10}(h_1/121.92)]$	$0.174(d_{\mathsf{km}} - 64.38))$

$$S_2(h_1,\, d_{\mathsf{km}}) = 0.00784|\mathsf{log}_{10}(9.98/d_{\mathsf{km}})|(h_1 - 300) \text{ for } h_1 > 300$$

$$S_3(f_{MHz}) = f_{MHz}/250\,\mathsf{log}_{10}(1500/f_{MHz})$$

$$S_4(f_{MHz},\, d_{\mathsf{km}}) = [0.112\,\mathsf{log}_{10}(1500/f_{MHz})](d_{\mathsf{km}} - 64.38) \text{ for } d_{\mathsf{km}} > 64.38$$

Walfisch-Ikegami Model

- In Europe, research under the Cooperation in the Field of Scientific and Technical Research (COST) program has developed improved empirical and semideterministic models for mobile radio propagation.

- In particular, Project 231 (COST 231), entitled "Evolution of Land Mobile Radio Communications," resulted in the adoption of propagation modeling recommendations for cellular and PCS applications by the International Telecommunications Union (ITU), including a semideterministic model for medium-to-large cells in built-up areas that is called the Walfisch-Ikegami model.

- The Walfisch-Ikegami model (WIM) has been shown to be a good fit to measured propagation data for frequencies in the range of 800 to $2{,}000$ MHz and path distances in the range of 0.02 to 5 km.

Walfisch-Ikegami model (continued)

- The WIM distinguishes between LOS and non-line-of-sight (NLOS) propagation situations.

- In a LOS situation, there is no obstruction in the direct path between the transmitter and the receiver, and the WIM models the propagation loss in dB by the equation

$$\mathsf{L}_{LOS} = 42.64 + 26 \log_{10} d_{km} + 20 \log_{10} f_{MHz}\,, \quad d_{km} \geq 0.02$$

  - Note that the propagation law (power of distance) for the LOS situation is modeled as being $26/10 = 2.6$, so that $\mathsf{L}_{LOS} \propto d^{2.6}$.

  - This model assumes that the base station antenna height (≥ 30m) ensures that the path has a high degree of Fresnel zone clearance. Recall that the propagation loss in free space is given by

$$\mathsf{L}_{fs} = 32.45 + 20 \log_{10} d_{km} + 20 \log_{10} f_{MHz}$$

  - The LOS propagation loss can be written as

$$\mathsf{L}_{LOS} = \mathsf{L}_{fs} + 10.19 + 6 \log_{10} d_{km} = \mathsf{L}_{fs} + 6 \log_{10}(50\, d_{km}) = \mathsf{L}_{fs} + 6 \log_{10}(d_m/20)$$

- For NLOS path situations, the WIM gives the path loss using the following parameters:

$$h_b = \text{Base antenna height over street level, in meters } (4 \text{ to } 50\text{m})$$

$$h_m = \text{Mobile station antenna height in meters } (1 \text{ to } 3\text{m})$$

$$h_B = \text{Nominal height of building roofs in meters}$$

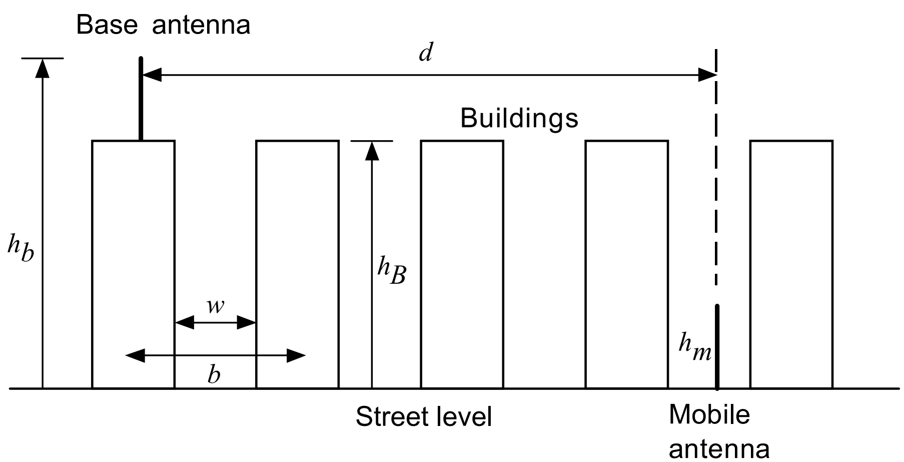
$$\Delta h_b = h_b - h_B = \text{Height of base antenna above rooftops in meters}$$

$$\Delta h_m = h_B - h_m = \text{Height of mobile antenna below rooftops in meters}$$

$$b = \text{Building separation in meters } (20 \text{ to } 50\text{m recommended if no data})$$

$$w = \text{Width of street } (b/2 \text{ recommended if no data})$$

$$\phi = \text{Angle of incident wave with respect to street (use } 90° \text{ if no data)}$$



Walfisch-Ikegami model (continued)

- In the absence of data, building height in meters may be estimated by three times the number of floors, plus 3 m if the roof is pitched instead of flat. The model works best for base antennas well above the roof height.

- Using the parameters listed above, for NLOS propagation paths the WIM gives the following expression for the path loss in dB:

$$\mathsf{L}_{NLOS} = \begin{cases} \mathsf{L}_{fs} + \mathsf{L}_{rts} + \mathsf{L}_{mds}\,, & \mathsf{L}_{rts} + \mathsf{L}_{mds} \geq 0 \\ \mathsf{L}_{fs}\,, & \mathsf{L}_{rts} + \mathsf{L}_{mds} < 0 \end{cases}$$

where

$$\mathsf{L}_{fs} = \text{Free-space loss} = 32.45 + 20\log_{10} d_{km} + 20\log_{10} f_{MHz}$$

$$\mathsf{L}_{rts} = \text{Roof-to-street diffraction and scatter loss, and}$$

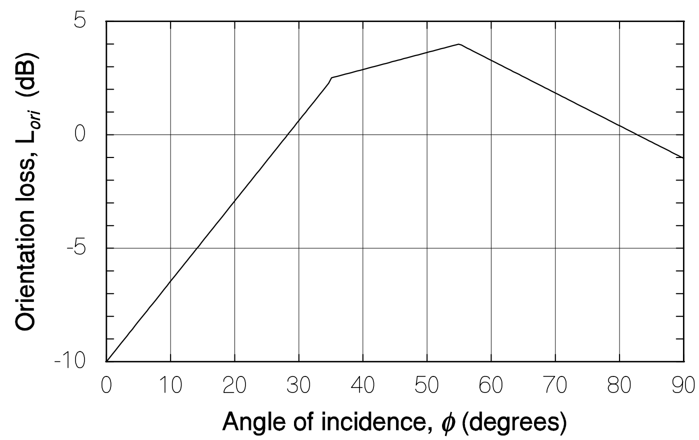
$$\mathsf{L}_{msd} = \text{Multiscreen diffraction loss}$$

- The loss terms L_{rts} and L_{msd} are functions of the NLOS parameters shown previously.

- The formula given for L_{rts} involves an orientation loss, L_{ori}:

$$\mathsf{L}_{rts} = -16.9 - 10\,\log_{10} w + 10\,\log_{10} f_{MHz} + 20\,\log_{10} \Delta h_m + \mathsf{L}_{ori}$$

where
$$\mathsf{L}_{ori} = \begin{cases} -10 + 0.354\,\phi, & 0 \leq \phi \leq 35° \\ 2.5 + 0.075(\phi - 35°), & 35° \leq \phi \leq 55° \\ 4.0 - 0.114(\phi - 55°), & 55° \leq \phi \leq 90° \end{cases}$$



- The formula given for the multiscreen diffraction loss term L_{msd} is

$$\mathsf{L}_{msd} = \mathsf{L}_{bsh} + k_a + k_d \log_{10} d_{km} + k_f \log_{10} f_{MHz} - 9 \log_{10} b$$

- In this expression, L_{bsh} is shadowing gain (negative loss) that occurs when the base station antenna is higher than the rooftops:

$$\mathsf{L}_{bsh} = \begin{cases} -18 \log_{10}(1 + \Delta h_b), & \Delta h_b > 0 \\ 0, & \Delta h_b \leq 0 \end{cases}$$

- L_{msd} decreases for wider building separation (b). The quantities k_a , k_d , and k_f determine the dependence of the loss on the distance (d_{km}) and the frequency (f_{MHz}).

- The term k_a in the formula for the multiscreen diffraction loss is given by

$$k_a = \begin{cases} 54, & \Delta h_b > 0 \\ 54 + 0.8\,|\Delta h_b|\,, & \Delta h_b \leq 0 \text{ and } d_{km} \geq 0.5 \\ 54 + 0.8\,|\Delta h_b|(d_{km}/0.5), & \Delta h_b \leq 0 \text{ and } d_{km} < 0.5 \end{cases}$$

This relation results in a 54-dB loss term if the base station antenna is above the rooftops $(\Delta h_b > 0)$, but more than 54 dB if it is below the rooftops. The increase from 54 dB is less if the link distance is rather small (less than 500m).

- The distance factor k_d in the formula for L$_{msd}$ is given by

$$k_d = \begin{cases} 18, & \Delta h_b > 0 \\ 18 + 15\,(|\Delta h_b|/h_B), & \Delta h_b \leq 0 \end{cases}$$

  - L$_{msd}$ increases with distance at 18 dB/decade if the base antenna is above the rooftops ($\Delta h_b > 0$). But if the antenna is below the rooftops, the increase is higher ($e.g.$, 30 dB per decade when it is only 20% as high as the buildings ($\Delta h_b/h_B = 0.8$).

- The frequency factor k_f in the formula for the multiscreen diffraction loss is given by

$$k_f = -4 + \begin{cases} 0.7\left(\frac{f_{MHz}}{925} - 1\right), & \text{medium city and suburban} \\ 1.5\left(\frac{f_{MHz}}{925} - 1\right), & \text{metropolitan area} \end{cases}$$

  - L$_{fs}$ and L$_{rts}$ together give an increase of 30 dB per decade of frequency. The expression for k_f indicates that this should be adjusted downward for $f < 6.21$ GHz for medium city and suburban environments or $f < 2.29$ GHz for a metropolitan area.

- For a typical cellular frequency of 850 MHz, the value of k_f is about -4 dB for either situation, so the total dependence on frequency for the 800-MHz cellular band is about 26 dB per decade.